Sunn-Hemp Utilized as a Legume Cover Crop for Corn Production

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ABSTRACT

The benefits of winter legumes as cover crops for corn (*Zea mays* L.) are diminished by the earliness of corn planting in relation to biomass and N production by the legumes. Tropical legumes may offer an alternative to winter legumes because they produce adequate biomass before corn planting. We determined the suitability of 'Tropic Sunn' sunn-hemp (*Crotalaria juncea* L.) as a cover crop for corn on a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) in central Alabama using a split-plot treatment structure in a randomized complete block design with four replications from 1991 to 1993. Main plots were winter fallow and sunn-hemp planted in mid-August, and subplots were N (0, 56, 112, and 168 kg N ha^{-1}) applied to corn 3 weeks after planting (WAP). Sunn-hemp biomass production approximately 14 WAP (first frost) averaged 7.6 Mg ha^{-1} with an N content of 144 kg ha^{-1} in the first 2 yr of the study. Corn grain yield following sunn-hemp averaged 6.9 Mg ha^{-1} whereas yield following winter fallow averaged 5.7 Mg ha^{-1}. Grain N averaged 16.3 kg ha^{-1} greater for corn following sunn-hemp than fallow plots. Before first frost, sunn-hemp produced excellent biomass to serve as a winter cover crop in corn production while producing N equivalent to 58 kg ha^{-1} of N fertilizer during the 3-yr period, based on corn yield and N response. Sunn-hemp has potential to be utilized as an alternative to winter legumes for ground cover and as an N source for a subsequent corn crop in the Southeast.

PREVIOUS RESEARCH highlights the benefits of utilizing a winter legume in a conservation tillage system for corn production (Mitchell and Teel, 1977; Ebelhar et al., 1984; Holderbaum et al., 1990; Decker et al., 1994). Winter legumes provide the same benefits of grass cover crops including erosion control, improved water infiltration, higher organic C contents, and cooler soil temperatures (Reeves, 1994), while simultaneously producing a source of biologically fixed N for subsequent crops like corn. The additional N supplied by winter legumes can reduce N fertilizer requirements (Ebelhar et al., 1984; Holderbaum et al., 1990). However, the N contribution of legumes is highly variable and depends on species, dry matter production, N concentration of the legume, indigenous soil N, and time of termination (Holderbaum et al., 1990; Reeves, 1994).

Time of termination has prompted researchers to focus on the synchrony of N release from legumes with the N uptake of corn (Decker et al., 1994; Stute and Posner, 1995; Mansoer et al., 1997; Vaughan and Evanylo, 1998). In a conservation tillage corn system, legumes are planted in the fall, allowed to mature over the winter, chemically terminated in the spring, and then corn is planted into the surface residue. Corn is typically planted early in the growing season, which forces an early termination date. A termination date at least 14 d before corn planting enables soil surface water recharge by planting time (Hargrove and Frye, 1987); however, as a result, biomass production for erosion control is limited and N release may not always synchronize with rapid N uptake of corn at the six-leaf stage (Magdoff, 1991). Decker et al. (1987) reported higher N percentages with increased legume top growth the longer the legume was allowed to grow in the spring.

An alternative to winter legumes are adapted tropical legumes, which produce higher biomass contents in temperate climates (Mansoer et al., 1997). Yadvinder et al. (1992) showed that tropical legumes could produce their biomass in a shorter time period compared with winter legumes. Reddy et al. (1986) showed mean biomass yields of 10 Mg ha^{-1} for several tropical legumes across a 3-yr full summer production period with mean N yields of 200 kg ha^{-1}.

A tropical legume that has been investigated as a green manure crop and as an intercrop for corn production in the tropics is sunn-hemp (Lales and Mabbayad, 1983; Jeranyama et al., 2000). 'Tropic Sunn', a sunn-hemp cultivar, was jointly released by USDA-NRCS and the University of Hawaii Institute of Tropical Agriculture and Human Resources in 1983. This legume can produce high amounts of biomass and symbiotic N in an 8- to 12-wk frost-free period (NRCS, 1999). Therefore, our objective was to determine if the rapid growth and N accumulation of sunn-hemp could serve as an alternative to winter legumes as a cover crop for conservation tillage corn production in the southern USA.

MATERIALS AND METHODS

We determined the suitability of Tropic Sunn sunn-hemp as a cover crop for corn on a Compass loamy sand at the Alabama Agricultural Experiment Station's E.V. Smith Research and Extension Center in Shorter, AL, using a split-plot treatment structure in a randomized complete block design with four replications from 1991 to 1993. Main plots were winter fallow and sunn-hemp planted in mid-August, with N (0, 56, 112, and 168 kg N ha^{-1}) applied as ammonium nitrate 3 WAP corn as subplots. Three replications from the fallow and sunn-hemp plots, designated to receive no N, mistakenly received 56 kg N ha^{-1} at 3 WAP in 1993. Consequently, those replications were eliminated from the analysis for that year. Winter weed growth was not controlled in fallow plots. All treatment combinations were in the same location each year with no re-randomization of treatments. Subplot dimensions were 3.7 m wide and 13.7 m long with a 0.3-m buffer between plots.

At the initiation of the experiment, in late summer of 1990, each main plot was sampled separately for a routine soil test

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Abbreviations: WAP, weeks after planting.

by compositing 20 soil cores (1.9 cm diam. probe) to correct any nutrient deficiencies that were present in the surface 20 cm of soil. Phosphorus, K, and Mg levels were high for each main plot based on the Mehlich I extractant (Mehlich, 1953) and the Auburn University Soil Testing Laboratory (Cope et al., 1983). Soil pH, measured in a 1:1 soil/water extract, indicated a recommendation of 0.91 Mg of limestone across the experimental area. Dolomitic lime was applied once in late summer of 1990 according to Auburn University Soil Testing Laboratory recommendations. Initial soil NH_4–N and NO_3–N concentrations were 3.1 and 1.7 mg kg^{-1} with an organic matter content of 11 g kg^{-1}. No additional commercial fertilizer was applied, with the exception of N, throughout the study.

All plots were disked, chisel-plowed, disked, and leveled before sunn-hemp planting each year. Sunn-hemp seed was treated with a commercial cowpea [*Vigna unguiculata* (L.) Walp.] rhizobium inoculant and planted at a seeding rate of 56 kg ha^{-1} on 15 Aug. 1990, 19 Aug. 1991, and 2 Sept. 1992 at a depth of 1.3 to 2.5 cm with a grain drill. Grain drill row spacing was 17.8 cm in 1990 and 10.2 cm in 1991 and 1992. As a result of different drill spacings among years, four sunn-hemp rows of equal length for biomass collected on 6 Nov. 1990 was from a 0.44 m^2 area, and sunn-hemp biomass collected on 8 Nov. 1991 was from a 0.31 m^2 area. Sunn-hemp biomass samples were collected in 1992, but the samples were misplaced before analysis. Dry matter production was comparable to the previous 2 yr. Aboveground biomass samples were oven-dried at 55°C for 72 h, weighed, and ground to pass a 1-mm screen with a Wiley mill[1] (Thomas Scientific, Swedesboro, NJ). Subsamples were analyzed for total N by dry combustion on a LECO CHN-600 analyzer[1] (Leco Corp., St. Joseph, MI).

Each plot was in-row subsoiled to a depth of 30 cm before planting corn (Dekalb 689) on 17 Apr. 1991, 14 Apr. 1992, and 14 Apr. 1993. Normal cultural practices to control insects and weeds were followed throughout the season. The center two rows of each plot were harvested with a small plot combine on 16 Aug. 1991, 24 Aug. 1992, and 19 Aug. 1993, and yields were adjusted to a moisture content of 155 g kg^{-1}. Total N content was determined on grain subsamples by dry combustion using the same procedure as the aboveground biomass samples.

Data were analyzed with year in the model and there were significant year × treatment interactions on response variables. Therefore, data were analyzed by analysis of variance using a general linear model procedure provided by Statistical Analysis System (SAS Inst., 2001) within each year, with data and discussion presented by year. The simplest best-fit linear or quadratic regression equations determined by the regression procedure provided by SAS were utilized to relate cover crops and N rates with selected dependent variables. Treatment differences were considered significant if $P > F$ was ≤ 0.10.

RESULTS AND DISCUSSION

Sunn-Hemp Biomass and Nitrogen Production

Sunn-hemp biomass, which was only collected during the first 2 yr of this experiment, averaged 7.6 Mg ha^{-1} at first frost approximately 14 WAP (Table 1). Sunn-hemp provided above average ground cover at the beginning of winter to protect the soil during a season when precipitation exceeds evapotranspiration, compared with the beginning of the summer growing season, when evapotranspiration typically exceeds precipitation. The amount of sunn-hemp biomass produced was greater than the minimum 4.5 Mg ha^{-1} rate, reported by Reiter et al. (2003), for a high-residue cereal crop conservation tillage system in Alabama and greater than reported dry matter produced from several winter legumes across Kentucky, North Carolina, and Georgia (Hoyt and Hargrove, 1986).

Table 1. Sunn-hemp dry matter production, N concentration, and N content measured at first frost from the E.V. Smith Research and Extension Center in Shorter, AL, during the 1991 and 1992 growing seasons. Sunn-hemp biomass samples were collected for the 1993 crop year, but samples were misplaced before analysis.

Year	Dry matter	N conc.	N content
	Mg ha^{-1}	g kg^{-1}	
1991	7.3 ± 0.8†	18.0 ± 1.4	129.4 ± 13.2
1992	7.8 ± 0.8	20.2 ± 1.5	157.9 ± 19.1
1993	–	–	–
Mean	7.6	19.1	143.7

† 95% confidence interval.

Aboveground N content of sunn-hemp for the first 2 yr of the experiment was 144 kg ha^{-1} at first frost (Table 1). This N content is comparable and in some cases higher than values for crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth), the standards by which most species are compared in most research of the Southeast (Reeves, 1994). Mansoer et al. (1997) reported an average sunn-hemp N content of 126 kg ha^{-1} for 3 site years, 9 to 12 WAP.

Corn Grain Yields

Corn grain yields were higher when planted into sunn-hemp than fallow plots for 2 of the 3 yr of the experiment (Table 2). When averaged over all years, corn yields were 1.2 Mg ha^{-1} higher for corn following sunn-hemp. Each incremental rate of N applied increased yields, averaged over both cover crops; however, a cover × N rate interaction occurred in 1991 (Table 2). Corn grain yields measured in sunn-hemp plots were higher than fallow plots at lower N rates, but corn grain yields from both covers were approximately equal at the highest N rate (Fig. 1). Fallow plots were also more responsive to each incremental increase of N applied. The response of corn grain yields following sunn-hemp with no additional N was above corn grain yields from fallow plots with 56 kg N ha^{-1} applied (Fig. 1). Mansoer et al. (1997) showed that sunn-hemp, mowed in the fall and overwintered under similar environmental conditions as our study, had 45 kg N ha^{-1} remaining at the time of corn planting the following spring. The higher response to sunn-hemp with no additional N may be attributed to the lack of mowing in our study, which would slow decomposition and subsequent release of N during winter, potentially increasing the N remaining at corn planting and the "rotation effect" observed following legumes (Hargrove and Frye, 1987; Reeves, 1994; Torbert et al., 1996).

[1] Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of a product to the exclusion of others that may be suitable.

Table 2. Corn grain yield and grain N contents measured for cover crop (main plots) and N rates (subplots) for 1991–1993 at the E.V. Smith Research and Extension Center in Shorter, AL.

Treatment	Corn grain yield 1991	Corn grain yield 1992	Corn grain yield 1993†	Grain N content 1991	Grain N content 1992	Grain N content 1993†
	Mg ha^{-1}			kg ha^{-1}		
Cover crop						
Fallow	5.2	5.7	6.3	61.2	71.2	81.3
Sunn-hemp	6.9	6.9	6.9	80.7	86.7	95.1
N rate, kg ha^{-1}						
0	3.8	1.9	2.8	41.7	20.9	34.7
56	5.8	6.0	4.8	63.6	73.2	56.3
112	6.9	8.3	7.4	80.4	103.9	95.5
168	7.8	9.0	8.5	98.2	117.8	128.0
			Analysis of variance ($P > F$)			
Cover crop	0.0308	0.0087	0.2340	0.0432	0.0091	0.0165
N rate, kg ha^{-1}	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cover × N rate	0.0001	0.2557	0.9064	0.0003	0.0721	0.7871

† Analyses for 1993 data includes only 26 observations due to a mistake in fertilizer application for three replications of fallow and sunn-hemp plots.

Corn Grain Nitrogen Contents

Corn grain N contents were higher following sunn-hemp than fallow plots for all 3 yr of the experiment (Table 2). The 3-yr average grain N content of corn following sunn-hemp was 16.3 kg ha^{-1} higher than when corn followed fallow. Similar to corn grain yields, a cover × N rate interaction occurred in 1991 and 1992. Corn grain N contents in 1991, following sunn-hemp with no additional N, were higher than grain N contents from fallow plots with 0 and 56 kg N ha^{-1} applied and approximately equal to grain N contents from fallow plots with 112 kg N ha^{-1} applied (Fig. 2A). In 1992, corn grain N contents were similar between main plots at the 0 and 168 kg N ha^{-1} rate (Fig. 2B). The largest corn grain N content difference between covers occurred with 112 kg N ha^{-1} applied. The best fit to the response of corn grain N content and N applied following sunn-hemp was quadratic, indicating that the corn grain N content was maximized in 1992.

No obvious explanation exists for the similar grain N contents measured between main plots in 1992 when no N was applied (Fig. 2B). Grain yields measured from those plots were low, but yields following sunn-hemp were 85% higher (2.4 vs. 1.3 Mg ha^{-1}) than yields from the fallow plots. The largest response to sunn-hemp without additional N occurred in 1991, probably resulting in higher amounts of stover production com-

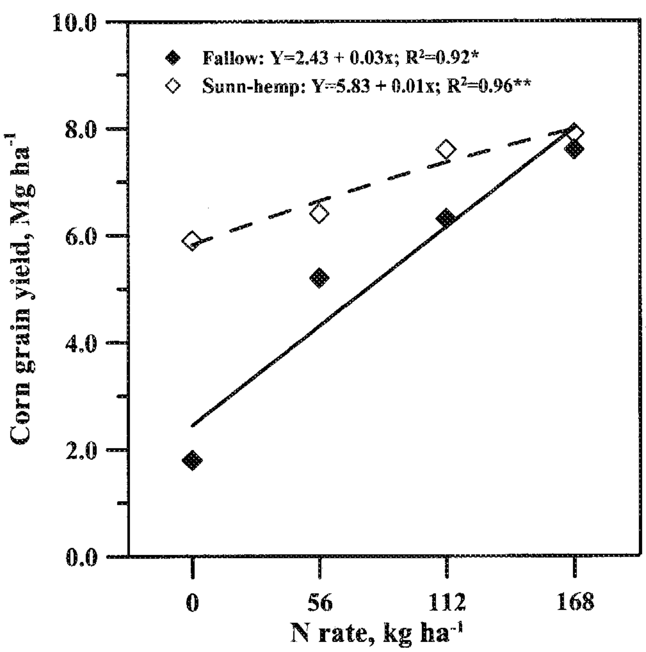

Fig. 1. Corn grain yields in 1991 following sunn-hemp and fallow plots measured across four N rates at the E.V. Smith Research and Extension Center in Shorter, AL.

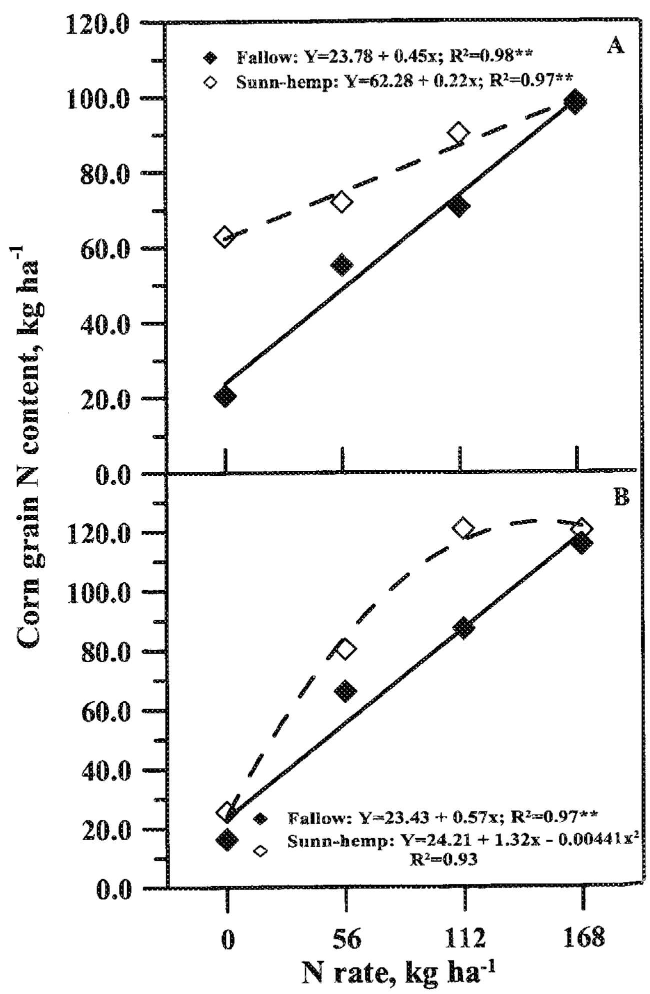

Fig. 2. Corn grain N contents following sunn-hemp and fallow plots measured across four N rates at the E.V. Smith Research and Extension Center in Shorter, AL, for (A) 1991 and (B) 1992.

pared with fallow plots. As a result, higher amounts of corn stover, with a high C/N ratio, were incorporated into the soil at the time plots were prepared for sunn-hemp planting, before the 1992 corn growing season. Incorporation of corn stover has been shown to promote immobilization of soil N (Smith and Sharpley, 1990; Aulakh et al., 1991). The high C/N ratio in stover may have immobilized indigenous soil N, N mineralized from sunn-hemp leaves, and in combination with the remaining sunn-hemp stems, which also have a high C/N ratio, attributed to the low grain N contents measured from sunn-hemp plots that received no additional N in 1992.

Estimated Sunn-Hemp Nitrogen Contribution

Regression equations relating corn grain yields and corn grain N content as a function of fertilizer N rate following fallow and sunn-hemp covers predicted the N fertilizer equivalence of sunn-hemp (Table 3). Based on corn grain yield regression equations, sunn-hemp produced an average N fertilizer equivalence of 58 kg ha^{-1} over the 3-yr period. This amount corresponds to the 45 kg N ha^{-1} reported by Mansoer et al. (1997), remaining in sunn-hemp residue at the time of corn planting after it was mowed in the fall and allowed to decompose over the winter. As previously discussed, the lack of mowing in our study may have slowed the decomposition process of sunn-hemp residue. In addition, the higher N content (18 kg ha^{-1}) of sunn-hemp residue from our study compared to that reported by Mansoer et al. (1997) may explain the higher N fertilizer equivalence observed.

Hargrove (1986) suggested that grain N content provided a better estimate of the N contribution from legumes because the response is generally linear over typical N rate ranges, and yield integrates other factors besides N contribution. Other authors also suggest that calculating N fertilizer equivalence with yield does not distinguish between the effect of the N contribution from the cover crop and other effects of the cover crop (Smith et al., 1987; Frye et al., 1988). These other yield enhancing effects are considered rotation effects and may include improvements in soil structure and reduction in diseases or other phytotoxic substances (Hesterman, 1988). In Hargrove's study, it should be noted that grain yields were not influenced by N rates following legumes, but grain N contents were. In contrast, we observed that both yields and grain N contents were affected by N rates following sunn-hemp, and grain N contents following sunn-hemp were not always linear over the range of N rates utilized in our study.

Regression equations for grain N content predicted an N fertilizer equivalence of 33 kg ha^{-1} for sunn-hemp. This number is misleading because the first year the value was 86 kg N ha^{-1}, but it was <15 kg N ha^{-1} for the last 2 yr. Nitrogen fertilizer equivalence predicted with regression equations for yield also decreased with each succeeding year (113, 38, and 24 kg N ha^{-1}). Reeves et al. (1993) suggested that total fertilizer N requirements may decrease with time due to the residual effects of legume N, and Torbert et al. (1996) stated that legume cover crops may improve fertilizer or native soil N utilization by corn. Since the experimental plots remained in the same position for the duration of the experiment, residual effects of N may have been more pronounced. However, if high residual N contents were present in the soil, corn yields following sunn-hemp would have a greater chance to plateau at the high N rate, indicating a maximum was achieved, especially for the last year. The linear regression equations indicate that 168 kg N ha^{-1} may not have maximized yields (Table 3).

Another explanation for the discrepancy of predicted N fertilizer equivalence among years may be the composition of the sunn-hemp residue present at planting and the amount of precipitation received as sunn-hemp decomposes. Mansoer et al. (1997) reported that the majority of the N in sunn-hemp is present in the leaves, which decomposed rapidly during the first 4 wk after mowing. The remaining residue consisted of stems, with a high C/N ratio, potentially lowering the N fertilizer equivalence of sunn-hemp. In our study, sunn-hemp was not mowed, but the leaf material probably decomposed quickly due to the previously reported low C/N ratio of the leaf fraction. As this decomposition occurred, mineralized N from sunn-hemp was susceptible to denitrification and leaching, primarily from winter precipitation because no crops were planted during the winter period to utilize the mineral N. Table 4 presents the precipitation amounts received during the period after sunn-hemp biomass collection in November to time of corn planting in April for the 3 yr of the study compared with the 30-yr mean. Precipitation received during the 4-wk period of November in 1990 was less than half the amount of precipitation received during the 30-yr mean

Table 3. Regression equations for corn grain yields and corn grain N content as a function of fertilizer N rate following fallow and sunn-hemp plots for 1991–1993 at the E.V. Smith Research and Extension Center in Shorter, AL.

Year	Fallow Equation	R^2	Model $P > F$	Sunn-hemp Equation	R^2	Model $P > F$
			Corn grain yields			
1991	$y = 2.43 + 0.03x$	0.92	0.0364	$y = 5.83 + 0.01x$	0.96	0.0190
1992	$y = 1.97 + 0.04x$	0.94	0.0286	$y = 3.47 + 0.04x$	0.87	0.0690
1993	$y = 2.42 + 0.04x$	0.98	0.0100	$y = 3.39 + 0.03x$	0.98	0.0116
			Corn grain N content			
1991	$y = 23.78 + 0.45x$	0.98	0.0098	$y = 62.28 + 0.22x$	0.97	0.0130
1992	$y = 23.43 + 0.57x$	0.97	0.0173	$y = 24.21 + 1.32x - 0.004x^2$	0.99	0.0761
1993	$y = 18.98 + 0.60x$	0.99	0.0003	$y = 26.72 + 0.66x$	0.99	0.0022

Table 4. Rainfall amounts for 1990–1991, 1991–1992, and 1992–1993 time periods and 30-yr means recorded at the E.V. Smith Research and Extension Center in Shorter, AL.

Month	Rainfall			
	1990–1991	1991–1992	1992–1993	30-yr mean†
	mm			
Nov.	46	126	272	112
Dec.	91	90	112	119
Jan.	166	167	73	133
Feb.	66	142	105	130
Mar.	223	90	164‡	170
Apr.	86	72	63	116
Mean	113	115	132	130

† 1971–2000 means.
‡ 10 additional cm of precipitation in the form of snow fell during this month.

for that same month. No measurements were taken to quantify mineral N contents, but the potential for denitrification and leaching losses was much lower for this period, which coincided with the highest N fertilizer equivalence measurement. Precipitation received during the 4-wk period of November in 1991 was approximately equal to the amount received during the 30-yr mean for the same month, increasing the potential for N losses. Nitrogen fertilizer equivalence also declined the second year. Precipitation received during the 4-wk period of November in 1992 was more than double the amount received during the 30-yr mean for the same month, coinciding with the lowest N fertilizer equivalence measured. These effects may explain the values observed in our study among N fertilizer equivalence values.

CONCLUSIONS

When compared with fallow, sunn-hemp produced higher corn grain yields 2 of the 3 yr with a weak trend ($P = 0.2340$) for higher yields the third year. Corn grain yields following sunn-hemp responded to N applications, but the response was less than yields following fallow plots. Corn grain N contents were higher following sunn-hemp than fallow for all 3 yr of the experiment. Calculated N fertilizer contribution from sunn-hemp averaged 58 kg N ha^{-1} based on corn yield and 33 kg N ha^{-1} based on grain content. These amounts appeared to be dependent on the amount of precipitation received after first frost, which terminated the sunn-hemp. Sunn-hemp, planted in mid- to late-August, can produce adequate biomass and significant amounts of N to replace winter annual legumes as a cover crop option for corn production in the humid Southeast. However, precipitation exceeds evapotranspiration during the winter months in this region, increasing potential for denitrification and leaching losses, and potentially decreasing the amount of N available from sunn-hemp residue for a succeeding corn crop. A winter cereal cover crop planted following sunn-hemp termination by frost could possibly utilize and sequester the N mineralized during winter from sunn-hemp, and thus, limit N losses and increase surface residue at corn planting.

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